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The Storage of Rice and Change of its Physical Properties during this Period.

By

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In general there are three methods of storing rice: (1) storage of unhulled rice or paddy (*Momi*), (2) storage of hulled rice (*Genmai*) and (3) storage of white rice (*Hakumai*). The storage of unhulled rice is of course the most safe method, but it is rarely done, because in our markets unhulled rice is not handled at all and it is a long standing custum to pay rent with hulled rice. White rice is not fitted for storage, because it can not be stored in safety long while. In Formosa, Korea, China, India and other countries the storage of unhulled rice is most common, but in Japan the storage of the hulled rice is most common. Since hulled rice is much damaged by insects and mould, a study of storing methods is important.

Since 1915 the writer has studied this problem with particular reference to the change of the physical properties of hulled rice while in storage. The results of the investigations have been reported in detail in Japanese[7] and in the present paper the writer want to describe these results briefly.

I. Temperature of rice in straw-bags.

Since the temperature of rice is a very important problem in rice-storage,

in the first place the writer made a study of the question from 1916 to 1925, using the several kinds of hulled rice which was stored in a granary of the Ōhara-Institute.

The temperature of the grain in straw-bags varies with the temperature of the granary according to the season. In summer the rice temperature is of course highest and in winter lowest. One example of the observations is given in the following.

In 1916—1919, during 4 years, the writer observed the temperature of hulled rice of "Shinriki" and at the same time the air temperature of the granary on the 15th of every month, at 10 a. m. The results are as follows: Table 1.

Table 1.

Temperature of rice and air temperature in the granary, at 10 a.m., 15th of every month (°C).

Month / Temperature	January	February	March	April	May	June	July	August	September	October	November	December
	°	°	°	°	°	°	°	°	°	°	°	°
Rice temp.[1]	4,2	4,4	6,9	12,4	16,2	21,2	26,3	28 2	25,5	19,7	12,4	8,0
Granary temp.[2]	5,0	4,9	7,2	12,9	16,4	20,9	25,3	27,0	22,4	17,4	11,8	7,7

Note. 1) Average of 9 samples; of 4 years.
2) Average of 4 years.

There is little variation in the temperature of rice in the course of a day; rather it is almost constant, but the temperature of the granary varies greatly in this time, just as the air temperature out of doors. The temperature of rice is therefore on the course of any one day not always equal to that of the granary itself.

The temperature of the rice always differs from the temperature of the granary. Generally, the former is higher than the latter in summer and autumn, and especially in September and October the difference in temperature is very great. For example, in September 1922 the comparative temperature of the rice and granary was taken with the following results. (See Table 2).

It was observed once, in September 1921, that the rice temperature at 10 a. m. was 7—10 degrees higher than that of granary.

In winter and spring on the contrary the rice temperature is lower than that of the granary and in January and February the difference between the respective temperatures is very great. In February 1922 the comparison was as follows: (See Table 3.)

Table 2.

Comparison of the rice and the granary temperature in September 1922 (°C).

Time / Temperature / Date	2 a. m.		6 a. m.		10 a. m.		2 p. m.		6 p. m.		10 p. m.	
	grana. temp.	rice temp.	grana. temp.	rice temp.	grana. temp.	rice temp.	grana. temp.	rice temp.	grana. temp.	rice temp.	grana. temp.	rice temp.
	°	°	°	°	°	°	°	°	°	°	°	°
Sept. 2, 1922 ...	28,5	29,7	27,9	29,7	28,0	29,7	28,8	29,5	29,5	29,8	29,4	29,8
„ 3 „ ...	28,8	29,9	28,0	29,8	28,3	29,7	29,0	29,7	29,3	29,9	29,7	30,0
„ 4 „ ...	28,3	30,0	28,2	30,0	28,7	30,0	28,9	30,0	28,7	30,0	28,3	30,0
„ 5 „ ...	28,2	30,0	28,2	30,0	28,0	29,9	28,6	29,9	29,0	29,9	28,9	30,0
Average	28,45	29,9	28,08	29,88	28,25	29,83	28,82	29,83	29,13	29,99	28,83	29,95
Difference between granary and rice temperature		+1,45		+1,8		+1,58		+1,0		+0,77		+1,12

Table 3.

Comparison of the rice and the granary temperature in February 1922 (°C).

Time / Temperature / Date	6 a. m.		10 a. m.		2 p. m.		6 p. m.		10 p. m.	
	grana. temp.	rice temp.	grana. temp.	rice temp.	grana. temp.	rice temp.	grana. temp.	rice temp.	grana. temp.	rice temp.
	°	°	°	°	°	°	°	°	°	°
Feb. 3, 1922	6,0	3,8	5,9	5,0	6,1	4,1	6,5	4,3	5,8	4,6
„ 4 „	6,0	4,9	5,1	4,8	5,8	5,2	6,1	5,2	5,3	5,1
„ 5 „	6,1	5,3	4,3	5,2	5,0	5,3	6,3	5,1	5,3	5,1
Average	6,03	4,67	5,1	5,0	5,63	4,87	6,3	4,87	5,47	4,93
Difference between granary and rice temperature		−1,36		−0,1		−0,76		−1,43		−0,54

In January 1918 at 10 a. m. the temperature of the rice was 2,9 degrees lower than that of the granary.

The air temperature in the granary increases in proportion to the height, and temperature of rice in straw-bags varies with the air temperature. (See Table 4). The grain in the higher position always having a higher temperature than that of the lower, it is therefore very important that the upper part of the building should be provided with sufficient ventilation to deduce the temperature. As it is above stated, in summer the rice temperature is higher than the granary temperature generally (See Table 2), but the writer observed that in the upper part of granary it is just contrary, the former is lower than the latter, because the temperature of the air increases much more than the rice

temperature with the increase of the height of a granary. In winter the rice temperature is always lower than the air temperature in every position of the granary. The results of the observations of the temperature and humidity in the different positions of the granary, in August 1924 and in February 1925 are given in Table 4.

Table 4.

Temperature of the rice and the granary (°C) and the relative humidity (%) in the granary air in August 1924 and February 1925, at 2 p. m.

No. of the grana.	Date of observation	Upper position			Middle position			Lower position			Maximum temp. of the out door
		rice temp.	grana. temp.	relat. humid	rice temp.	grana. temp.	relat. humid.	rice temp.	grana. temp.	relat. humid.	
		°	°	%	°	°	%	°	°	%	°
1.	August 13. 16 & 18. 1924	30,4	32,5	51,7	29,9	30,8	65,7	28,4	28,3	78,0	37,1
2.	August 20. 21 & 26. 1924	29,1	29,9	74,3	28,6	28,5	83,3	27,9	26,9	92,3	34,7
3.	February 10, 11, 12, & 13. 1925	4,7	5,6	59,1	4,3	5,1	62,6	4,0	4,8	65,0	6,6

Hulled and unhulled grain differ in temperature, unhulled grain (*Momi*) in straw-bags, according to the observation, in summer and autumn being a little lower than that of hulled grain (*Genmai*). The following table shows the results.

Table 5.

Comparison of the temperature of hulled and unhulled rice (paddy).

Sample	July			August			September			October		
	grana. temp.	rice temp.	difference	grana. temp.	rice temp.	difference	grana. temp.	rice temp.	difference	grana. temp.	rice temp.	difference
hulled rice[1]	25,3	26,4	+1,1	27,0	28,3	+1,3	22,4	25,4	+3,0	17,4	19,6	+2,2
paddy[2] ...	25,4	26,1	+0,7	27,1	27,1	0	22,6	24,0	+1,4	17,4	18,8	+1,4

Note. 1) Average of 3 samples, observation of 1916—1919.
2) 1 sample, observation of 1916—1919.

The temperature of rice varies mainly with the air temperature of the granary as stated already, but, the moisture of rice and various kinds of insects in the straw-bags play a great roll in the raising of temperature of rice. If the moisture of rice is more, then the temperature is higher, as may be already known. This is especially noticeable in summer and autumn, but not in winter. From the point of view of the moisture the humidity of the air in a granary must be noticed. It was observed that the humidity of the air in a granary decreases with the height as Table 4 shows, and is greatest in the

lower part of the granary. It must be therefore very important by some equipment to dry the air in the lower part of the granary.

Several kinds of insects in the straw-bags, especially *Calandra Oryzae*, which is in summer very numerous, raise the temperature of the rice to a great degree. In October 15, 1921 it was observed that the temperature of hulled rice, much infested by *Calandra Oryzae*, was 26,3°C and that the temperature of the granary was 16,8°C, or a difference of 9,5°C. Rice in the straw-bags was fumigated with Carbon-disulphide and 80% of the insects were destroyed. After 4 days the temperature was registered again, the rice being 22,7°C and the granary 19,6°C or a difference of 3,1°C, which shows that the presence of insects causes an increase in temperature to a great degree.

For the storage of grains, especially for the problem of the temperature and moisture, it is also very important to consider the relation between the outdoor air and the air inside the granary. Care should be taken to open the doors of the granary when the out-door air is drier and cooler than the air inside, but to keep the doors shut when the contrary is the case.

II. Moisture of rice.

When the rice contains much moisture, the respiration and self heating of grains become active, insects and micro-organisms thrive and the quality of rice deteriorates. Therefore rice must always be as dry as possible. As the moisture of rice is affected by the atmospheric humidity in a great degree, the variation of moisture of rice grains during the time of storage was studied. From 1915 to 1922 several kinds of hulled rice with different moisture were stored in straw-bags, in a granary of the institute, and the variation in the moisture was studied during the time of storage, with the following results.

The moisture of rice varies greatly, according to the season, being greatest in June and July and least in December and January. The difference between the maximum and minimum moisture in the course of a year is by the grains of moisture of 11% actually 3,4%, but by the grains of moisture of 15% only 1%. The moisture of the unhulled rice varies also owing to the season, just like hulled rice.

If various kinds of rice of different moisture are stored together in a granary, the moisture gradually varies affected by the atmospheric humidity. The different moisture apporoach to each other and after 2 or 3 years finally almost coincide. The rice, that was driest, gets most water, and it is therefore very important to protect it from moisture while in storage. The following facts are very interesting. After 4 or 5 years the rice loses water gradually and becomes dry, owing to the decrease of water holding ability of the grains. Then it was observed that the rice, that was driest in the beginning, loses most water, the one, that was moist in the beginning, loses least water, and at last

the moisture of rice became very different according to the degree of dryness of the rice in the beginning. An example of the results of the experiments is given in the following table.

Table 6.

Variation of moisture of the hulled rice during the time of storage.

Time \ Sample	A	B	C
	%	%	%
January 1917	14,14	12,78	11,11
February „	14,47	13,50	12,61
March „	14,60	13,99	12,82
April „	14,54	14,05	13,17
May „	14,66	14,18	13,48
June „	15,02	14,13	13,74
July „	15,28	14,72	14,37
August „	14,95	14,53	14,11
September „	14,68	14,31	14,11
October „	14,98	14,90	14,43
November „	15,36	14,77	14 49
December „	14,65	14,10	14,23
February 1918	15,42	15,35	15,28
March „	15,42	15,38	15,37
April „	15,48	15,40	15,33
May „	15,45	15,38	15,36
June „	15,43	15,36	15,25
July „	15,43	15,35	15,28
August „	15,53	15 80	15,57
September „	15 73	15,60	15,60
October „	16,08	16,03	16,07
November „	16,02	15 84	15,78
December „	15 93	15,87	15,83
February 1919	15,53	15,45	15,40
March „	15,45	15,38	15,32
April „	15,45	15,42	15,32
May „	15,33	15,25	15,02

Time \ Sample	A	B	C
	%	%	%
June 1919	15,65	15,62	15,35
July „	15,17	15,03	14,97
August „	15,17	14,95	14,88
September „	14,92	14,70	14,55
October „	14,73	14,57	14,47
November „	14,67	14,57	14,43
December „	14,65	14,47	14,45
January 1920	14,65	14,47	14,42
February „	14,70	14,43	14,30
March „	14,98	14,75	14,43
April „	15,00	14,67	14,45
May „	15,00	14,53	14,47
June „	15,40	14,90	14,50
July „	15,28	14,80	14,30
August „	15,20	14,67	14,13
September „	14,97	14,57	13,97
October „	14,93	14,33	13,80
November „	14,60	14,27	13,77
December „	14,53	14,23	13,63
January 1921	14,47	14,13	13,50
February „	14,40	14,03	13,47
March „	14,47	14,10	13,58
April „	14,48	14,10	13,57
May „	14,67	14,30	13,80
June „	15,10	14,77	14,30
July „	14,90	14,47	14,17
August „	14,70	14,33	13 93
September „	14,63	14,23	13,77
October „	14,50	14,15	13,67
November „	14,40	13,80	13,48
December „	14 20	13,60	13,35
January 1922	14,07	13,47	13,03
February „	14,18	13,60	13,20

As above stated, the moisture of rice will increase in a great degree, when the air humidity of the granary increases, especially in June and July. For the storage of the hulled rice, it is therefore very important to protect it from moisture. To tighten the straw-bag or to dry the air in the granary by some equipment is for instance one method.

From Table 6 we see however that if the rice are stored during several years in straw-bags and in a granary, the moisture of rice decreases gradually during the time that they are stored, owing to the decrease of the water holding capacity itself. When rice is stored a long time, it becomes dry and very hard.

III. Volume weight of rice.

KONDO[6] has studied the volume weight of rice. The volume weight of hulled rice grains is influenced by different factors. The relationship between volume weight and these factors are as follows: Factors causing an increase in volume weight are smooth seed coat, thick, round, short elliptical grains; the addition of small grains; mixing of large and small grains of the same kind; and sun or oven drying of the unhulled rice before hulling. Factors which cause a decrease in volume weight are a rough seed coat; long slender grains; broken or shrunken grains, straw, chaff, etc; drying the hulled rice by the sun's heat or by means of chemicals; and the absorption of water. The one factor which exerts no definite influence is size of grains. In the present paper the effect of the season and length of time of storage on the volume weight of hulled rice was studied.

The volume weight of hulled rice grains varies greatly according to the season; in July, August, September it is small, and in August least, and in January and February great, especially in January greatest; since it is greatly affected by the atmospheric humidity. As in summer the atmosphere is moist and hot, the volume weight of hulled rice grains becomes smaller, while in winter, on the contrary, it is dry and cool, the volume weight of the grains becomes greater. It is well known that the volume of rice in straw-bags increases in May—August (wet season) and decreases in October—November (dry season). This fact coincides with the above results of the experiments.

The following is an example of the experiments:

From January 1917 to February 1922, 9 samples of hulled rice of "Kibiho" of different moisture was stored in straw-bags and in a granary of the institute. The volume weight of every sample was taken monthly. The average of 9 samples covering 4 years is given in Table 7.

Table 7.

Volume weight of hulled rice of "Kibiho", average of 9 samples of 1917—1921.

(Weight of a hectolitre)

January	February	March	April	May	June	July	August	September	October	November	December
kg 85,82	kg 85,49	kg 85,48	kg 85,15	kg 85,25	kg 84,76	kg 84,29	kg 83,89	kg 84,18	kg 84,00	kg 84,55	kg 84,19

The volume weight of unhulled rice varies, like hulled rice, according to the season. In winter it is great, especially in January the greatest, in summer small, especially in August the least. But this variation is not so much like that of the hulled rice, owing to the stiffness of the husks.

When the hulled rice is stored during many years, volume weight varies in a great degree, according to the number of years of storage. For instance, according to the experiment the volume weight of rice in straw-bags in a granary increases gradually during 4 years generally, because the grains become dry year after year. But in the fifth year it decreases suddenly, because the grains were damaged by insects heavily.

The following table is an example:

Table 8.

Volume weight of hulled rice of "Kibiho", average of 9 samples.

(Weight of a hectolitre)

1917	1918	1919	1920	1921
1st year	2nd year	3rd year	4th year	5th year
kg 84,02	kg 85,06	kg 85,43	kg 85,79	kg 83,61

IV. Water absorbing capacity and swelling ability in water of rice.

The writer studied the variation of the water absorbing capacity and swelling ability in water of rice stored several years. From 1915 to 1922 several kinds of hulled rice (*Genmai*) in straw-bags were stored in a granary of the institute. In the experiments 50 grs. of rice from every bag are taken and soaked in water of 25—28°C for 48 hours. It is a matter of course that the rice grains then increase greatly in volume and weight. The writer carried on

the experiments every month during the time of storage and found that the percentage of increase in weight (= water absorbing capacity) and volume (= swelling ability in water) is variable according to the length of storage, as the following results show.

The writer investigated the water absorbing capacity and the swelling ability in water of rice of "Kibiho" of 9 samples (= 9 straw-bags) and "Shinriki" of 10 samples (= 10 straw-bags) and found that they decrease regularly with the length of storage as Table 9 shows.

Table 9.

Swelling ability and water absorbing capacity of water-soaked rice grains of "Kibiho".

Time	Length of storage	Swelling ability in water				Water absorbing capacity			
		A	B	C	Average of A. B. C	A	B	C	Average of A. B. C
	months	%	%	%	%	%	%	%	%
January 1917	0,5	39,4	46,6	42,7	42,9	29,3	33,7	34,2	32,4
February „	1,5	42,9	45,7	46,7	45,1	31,5	33,3	33,3	32,7
March „	2,5	46,3	49,2	49,3	48,3	32,8	35,3	35,0	34,4
April „	3,5	43,3	44,4	43,3	43,7	30,9	31,3	32,3	31,5
May „	4,5	42,7	45,3	44,6	44,2	30,7	31,5	31,1	31,1
June „	5,5	39,3	42,8	41,7	41,3	28,2	31,3	31,6	30,4
July „	6,5	40,2	40,3	38,5	39,7	29,3	29,1	28,7	29,0
August „	7,5	39,4	41,0	41,1	40,5	27,9	28,7	28,2	28,3
September „	8,5	36,8	37,3	38,2	37,4	26,9	28,3	27,1	27,4
October „	9,5	36,9	37,1	38,0	37,3	27,3	27,6	27,7	27,5
November „	10,5	34,4	35,9	37,2	35,8	26,1	26,3	26,9	26,4
December „	11,5	36,5	37,2	37,0	36,9	26,6	27,5	27,6	27,2
January 1918	12,5	36,4	37,6	36,6	36,9	27,3	28,3	27,4	27,7
February „	13,5	34,8	36,4	35,9	35,7	27,5	28,7	28,0	28,1
March „	14,5	34,6	35,4	35,2	35,1	24,9	25,5	25,4	25,3
April „	15,5	32,9	34,5	35,5	34,3	25,4	25,9	26,1	25,8
May „	16,5	32,7	33,6	34,3	33,5	25,0	25,5	25,8	25,4
June „	17,5	31,6	33,2	33,3	32,7	24,0	25,1	25,2	24,8
July „	18,5	32,9	33,4	34,1	33,5	24,8	25,2	25,5	25,2
August „	19,5	32,7	32,1	32,2	32,3	24,2	24,5	24,3	24,3
September „	20,5	31,5	31,6	31,7	31,6	24,2	24,3	24,3	24,3
October „	21,5	29,8	30,6	30,7	30,4	23,5	23,9	23,9	23,8
November „	22,5	32,0	31,9	32,2	32,0	24,4	24,5	24,5	24,5
December „	23,5	30,7	31,3	31,4	31,1	24,3	24,4	24,5	24,4
February 1919	25,5	32,1	32,5	32,9	32,5	24,7	24,7	24,8	24,7
March „	26,5	31,5	31,7	32,1	31,8	24,0	24,2	24,3	24,2

Time	Length of storage	Swelling ability in water				Water absorbing capacity			
		A	B	C	Average of A. B. C	A	B	C	Average of A. B. C
	months	%	%	%	%	%	%	%	%
April 1919	27,5	34,0	31,2	31,7	31,3	24,6	24,6	24,8	24,7
May „	28,5	31,7	32,0	32,2	32,0	24,5	24,5	24,7	24,6
June „	29,5	30,6	30,9	31,3	30,9	23,8	24,0	24,0	23,9
July „	30,5	32,5	33.3	34,1	33,3	25,3	25,7	25,7	25,6
August „	31,5	31,4	32,0	31,8	31,7	24,5	24,6	24,7	24,6
September „	32,5	30,6	31,1	31,0	30,9	24,5	24,6	24,5	24,5
October „	33,5	30,6	31,0	31,4	31,0	24,6	24,4	24,7	24,6
November „	34,5	30,3	30,7	30,9	30,6	24,2	24,1	24,5	24,3
December „	35,5	29,1	29,3	29,9	29.4	23,3	23,0	23,4	23,2
January 1920	36,5	29,4	29,1	29,4	29,3	23,6	23,7	23,7	23,7
February „	37,5	29,3	29,0	29,6	29,3	23,2	23,3	23,6	23,4
March „	38,5	26,6	27,7	28,1	27,5	22,7	22,9	22,9	22,8
April „	39,5	28,0	28,0	28,2	28,1	22,6	22,7	22,8	22,7
May „	40,5	29,1	29,9	29,9	29,6	23,9	24,0	24,2	24,0
June „	41,5	29,8	30,2	30,4	30,1	24,3	24,4	24,4	24,4
July „	42,5	28,7	29,0	29,9	29,2	23,9	23,7	23,7	23,8
August „	43,5	28,6	29,1	29,0	28,9	23,8	23,7	23,6	23,7
September „	44,5	28,8	29,3	29,4	29,2	23,3	23,2	23,3	23,3
October „	45,5	29,1	29,9	30,1	29,7	23,1	23,3	23,3	23,2
November „	46,5	29,4	29,7	30,3	29,8	23,1	23,1	23,3	23,2
December „	47,5	29,5	30,0	30,4	29,9	23,1	23,1	23,3	23,2
January 1921	48,5	29,5	30,0	30,5	30,0	23,2	23,1	23,3	23,2
February „	49,5	27,9	28,2	28,6	28,2	23,2	23,3	23,3	23,3
March „	50,5	28,1	28,3	28,4	28,3	22,9	23,0	23,2	23,0
April „	51,5	27,6	27,5	27,6	27,6	22,9	23,1	23,2	23,1
May „	52,5	27,2	27,4	27,8	27,5	23,0	23,0	23,2	23,1
June „	53,5	27,0	27,1	27,4	27,2	22,8	23,0	23,3	23,0
July „	54,5	27,1	27,3	27,9	27,4	22,9	23,3	23,3	23,2
August „	55,5	26,4	27,1	27,6	27,0	23,2	23,1	23,0	23,1
September „	56,5	27,8	28,2	27,7	27,9	24,5	24,1	24,0	24,1
October „	57,5	28,3	28,8	28,6	28,6	24,6	24,6	24,8	24,7
November „	58,5	28,4	28,4	29,2	28,7	24,8	25,0	25,0	24,9
December „	59,5	30,6	30.2	31,6	30,8	26,4	26,2	26,4	26,4
January 1922	60,5	31,3	31,4	32,0	31,6	25,8	26,0	26,5	26,1
February „	61,5	30,6	30,7	30.9	30,8	24,5	24,5	24,4	24,5

The description of the results about "Shinriki" is omitted here entirely because the results about "Shinriki" are just like them about "Kibiho" in Table 9.

As is above stated, the water absorbing capacity and swelling ability in water of rice grains, which are stored in straw-bags, decreases regularly with the length of storage. Let x be the number of month, during which the rice grains are stored, let y be the percentages of increase in volume or weight and let a and n be constants, then there will result the following equation: $y = ax^n$.

By experiments and calculations the constants a and n can be determined. Take any hulled rice in storage. If the percentages of increase in volume or weight of grains in water are investigated, then the number of months of storage of the rice grains can be easily found by the equation, which were determined. By the writer's experiments and calculations about "Kibiho" and "Shinriki" the following equations in Table 10 are obtained:

Table 10.

$y = ax^n$.

No.	Samples	Moisture of rice in the beginning of storage	Equations	
			Swelling ability	Water absorbing capacity
		%		
1.	*Kibiho* A (average of 3 samples)	14,14	$y=52{,}43\,x^{-0{,}154}$	$y=33{,}90\,x^{-0{,}0873}$
2.	„ B „	12,78	$y=57{,}03\,x^{-0{,}172}$	$y=36{,}70\,x^{-0{,}107}$
3.	„ C „	11,11	$y=55{,}88\,x^{-0{,}166}$	$y=36{,}44\,x^{-0{,}103}$
	„ (average of No. 1—No. 3)	12,68	$y=54{,}94\,x^{-0{,}162}$	$y=35{,}73\,x^{-0{,}0993}$
4.	*Shinriki* A (average of 3 samples)	14.53	$y=45{,}3\,x^{-0{,}1222}$	$y=32{,}86\,x^{-0{,}1028}$
5.	„ B (average of 4 samples)	12,17	$y=51{,}36\,x^{-0{,}154}$	$y=36{,}72\,x^{-0{,}1333}$
6.	„ C (average of 3 samples)	11,0	$y=52{,}57\,x^{-0{,}1578}$	$y=38{,}36\,x^{-0{,}1457}$
	„ (average of No. 4—No. 6)	12,57	$y=50{,}75\,x^{-0{,}1506}$	$y=36{,}69\,x^{-0{,}133}$

Note. "Kibiho" are stored in the space of five years and "Shinriki" three years.

Beyond question the moisture of rice grains has an effect upon the water absorbing capacity and swelling ability, as may already be known, but this effect is much less than that caused by the length of storage. In the following table the writer will show the relationship between the moisture of rice and the water absorbing capacity and swelling ability.

Table 11.

Relationship between the moisture of rice and the water absorbing and swelling ability of "Kibiho", Average of 9 samples.

Year	Moisture of hulled rice	Swelling ability	Water absorbing capacity
	%	%	%
1917, 1st year of storage	14,2	41,1	29,9
1918, 2nd „ „ „	15,6	33,3	25,3
1919, 3rd „ „ „	15,0	31,4	24,4
1920, 4th „ „ „	14,6	29,3	23,4
1921, 5th „ „ „	14,2	28,3	23,7

From the above table it is seen that, notwithstanding the moisture of rice decreases yearly, but the swelling ability and water absorbing capacity of rice do not increase, on the contrary they decrease regularly with the length of time. It shows that the effect of moisture is much less than that of length of storage.

The writer investigated the seasonal variation of the water absorbing capacity and swelling ability of water soaked hulled rice of "Kibiho" and "Shinriki" with the following results:

Table 12.

Monthly variation of the water absorbing capacity and swelling ability of the hulled rice of "Kibiho", average of 9 samples and 5 years.

	January	February	March	April	May	June	July	August	September	October	November	December
	%	%	%	%	%	%	%	%	%	%	%	%
Swelling ability	34,4	34,2	34,2	33,0	33,4	32,4	32,6	32,1	31,4	31,4	31,4	31,6
Water absorbing capacity	26,4	26,4	25,9	25,6	25,6	25,3	25,4	24,8	24,7	24,8	24,7	24,9

According to Table 12 the water absorbing capacity and swelling ability of rice decrease regularly and notwithstanding the seasonal variation in the moisture (see II), the swelling ability and water absorbing capacity vary only slightly with the season. From the above described facts the conclusion is reached that the decrease of the water absorbing ability and swelling capacity of the water soaked rice is caused mainly by ageing.

PAYEN[8] found that, when wheat, rye, barley and oats are moistened, the percentage of increase in volume is greater than that of the weight. The writer observed also the same fact about rice. When rice is soaked in water

as above stated, the percentage of increase in volume is much greater than that of the weight, as Table 13 shows.

Table 13.

Comparison of the percentage of increase in volume and that in weight of hulled rice soaked in water. Average of 9 samples of "Kibiho" and 10 samples of "Shinriki".

	1st year of storage	2nd year of storage	3rd year of storage
	%	%	%
Swelling ability	40,7	33,3	31,0
Water absorbing capacity	28,6	25,2	24,0

Notice: See Table 11.

It may be added that the decrease in swelling ability and water absorbing capacity, as above explained, is mainly caused by the ageing of the colloidal substances of the rice, as the same phenomena may be seen in other colloidal materials.

V. Hardness of rice.

The hardness of the grains is one of the important properties of rice. When the hardness of the grains is increased, the keeping quality is improved, and in producing white rice the material lost is decreased. It is well known, that the hardness is affected by the moisture in a great degree. If the moisture of rice is small, then the hardness is increased. An example for it is as follows: This was determined in the following manner. 19 samples of hulled rice, "Kibiho" and "Shinriki" with different moisture, soon after harvest were tested by Kitao's instrument. When a grain is broaken under pressure the pressure weight is taken as hardness.

The hardness is generally denoted by *kg*.

The following results were obteined.

Table 14.

Relationship between the moisture and the hardness of rice grains, 1917.

Kibiho	Moisture (%)	15,30	13,84	13,29	13,27	12,60	12,48	11,56	10,94	10,84	—
	Hardness (kg)	5,396	5,867	5,932	5,879	5,793	6,236	6,086	5,993	7,154	—
Shinriki	Moisture (%)	15,12	14,65	14,49	14,22	13,70	13,58	12,67	12,15	12,27	12,21
	Hardness (kg)	5,438	5,750	6,736	6,487	7,118	6,887	7,143	6,678	6,780	6,971

Heretofore the relationship between the duration of storage and the hardness of the grains has been undetermined, as no experiment has been made. The idea prevails, that the hardness of rice stored in straw-bags decreases as it becomes older, which is incorrect. For the first and two or three years the hardness of the grains does decrease but after several years it increases again, as Table 15 shows.

Table 15.

Hardness of rice grains, "Kibiho", average of 9 straw-bags.

1917	1918	1919	1920	1921
1st year of storage	2nd year of storage	3rd year of storage	4th year of storage	5th year of storage
kg 5,25	kg 4,78	kg 4,80	kg 5,18	kg 5,39

According to the season, the hardness of rice grains varies greatly; from July to September it is least, from November to January or February greatest; since it is greatly affected by the atmospheric humidity. The variation of hardness of the grains according to the season can be seen in Table 16.

Table 16.

Hardness of rice grains in every month, "Kibiho".

Sort	January	February	March	April	May	June	July	August	September	October	November	December
Kibiho[1]	kg 5,454	kg 5,265	kg 5,138	kg 5,176	kg 4,992	kg 4,875	kg 4,915	kg 4,851	kg 4,839	kg 5,151	kg 5,159	kg 5,282

Note. 1) Average of 9 samples covering 5 years, 1917—1921.

VI. Material lost by polishing rice.

The material lost by polishing (skinning) rice is one of the problems of storage. Generally it is thought that the material lost by polishing increases in a great degree with the length of the time of storage, if the hulled rice is stored in straw-bags and in a granary. But according to the experiment, if the rice is stored without the damage of insects and mould, the material lost does not increases, rather it decreases with the length of time of storage, because the grains will get drier and harder the longer it is stored.

According to the season, the material lost by polishing varies greatly. In July and August it is greatest and from December to February least,

because it is greatly affected by the atmospheric humidity as shown by the following examples:

Table 17.

Material lost by polishing of hulled rice.

(% in Weight)

Month / Sort	January	February	March	April	May	June	July	August	September	October	November	December
	%	%	%	%	%	%	%	%	%	%	%	%
Kibiho 1)	6,65	6,13	6,69	6,90	7,08	7,29	7,71	7,60	7,33	6,86	6,96	6,48
Shinriki 2)	5,68	7,01	8,60	6,86	7,33	8,48	10,69	11,36	9,83	6,95	6,42	4,84

Note. 1) Average of 9 Samples covering 4 years.
2) „ „ 10 „ „ 2 „

From the point of view of the material lost by polishing it is important to keep the rice dry and protect it against insects and mould during while in storage and also not to polish it in summer. So far as the loss in polishing is concerned limit of length of time for storage may be not taken into account.

VII. Germination power of rice.

In 1916 and 1917 the effect of time of storage on germination was studied. The rice was stored in straw-bags as usual in a granary of the institute. The results of the experiments are given in Table 18.

Table 18.

Germination prower of rice.

A.

Time \ Samples	hulled rice Shinriki 1)	unhulled rice Shinriki 2)	Note
	%	%	
April 1916	95,6	96,3	1) Average of
May „	94,7	92,3	Samples of 9
June „	63,5	88,3	straw-bags
July „	54,2	82,8	2) 1 Sample
August „	11,3	80,3	
September „	9,5	44,5	
October „	0,6	12,3	
November „	0	10,0	
December „	0	7,5	
January 1917	0	5,0	
February „	0	6,8	

B.

Time \ Samples	hulled rice Kibiho[1]	hulled rice Shinriki[2]	Note
	% *	% *	
January 1917	95,7 + 1,4	—	1) Average of
February „	95,6 + 2,3	94,8 + 2,0	Samples of 9
March „	90,3 + 5,7	93,3 + 2,5	straw-bags
April „	97,2 + 0,8	95,8 + 1,9	2) Average of
May „	95,7 + 1,4	94,2 + 1,3	Samples of 10
June „	75,0 + 5,5	80,9 + 4,1	straw-bags
July „	81,4 + 3,8	72,6 + 4,0	
August „	24,6 + 3 3	33,3 + 3,3	
September „	2,8 + 1,5	4,2 + 0,9	
October „	0,1 + 0,1	0 + 0,1	
November „	0	0	

* Deformed germination.

The above table shows that the hulled rice in straw-bags retains their germination power until May more than 95% germinating, but from June—July it decreases; in June—July the germination power is ca 60—80%, in August 11—30%, in September only 5—10%, in October less than 1% and in November 0%. The germination period of hulled rice in straw-bags in a granary is scarcely one year.

The germination power of unhulled rice is retained longer than that of hulled rice. However it decreases from June—August gradually, in September suddenly and in October more markedly. In October the germination power is 12% and in November—February less than 10%.

From the point of view of the germination power the hot season, especially August—September, is the dangerous time for the storage of rice. By this study about storage the writer found also that some kinds of enzymes in the rice grains, diastase, lipase and peroxidase lose their activity in July—August suddenly. A description about it is omitted here entirely.

VIII. Other qualities of rice.

In this study of storing rice, the writer also investigated some other qualities of rice: weight of 1,000 grains, volume-increase of rice boiled in a kettle, taste of boiled rice, viscosity of rice paste and activities of several kinds of enzymes in rice. These qualities vary in a great degree during the time of storage. The results of these investigations are reported briefly in the following.

The variation of weight of 1,000 grains is chiefly affected by the variation of moisture of rice, which according to the season varies greatly. In spring and summer the weight of rice grains remains constantly or sometimes it increases slightly, in autumn and winter it decreases. Material lost by respiration and damages by insects and micro-organisms has also a great effect upon the decrease of the weight of grains. Generally speaking the weight of the rice grains decreases gradually while in storage, because the grains become drier and the material lost by several causes increases after long storage. The variation of the weight of unhulled rice is same as that of the hulled rice.

When the white rice is boiled in a kettle its volume increases greatly. The percentage of increase in volume of boiled rice to the original volume of white rice $\left(\frac{\text{Volume of boiled rice} - \text{Volume of white rice}}{\text{Volume of white rice}} \times 100\%\right)$ is called "Kamabue". The relationship between "Kamabue" and the length of time of storage was studied. Several kinds of rice stored in straw-bags being used, "Kamabue" of rice increases regularly with the length of time of storage, as the following table shows.

Table 19.

Kamabue.

Samples	1917	1918	1919	1920
	1st year of storage	2nd year of storage	3rd year of storage	4th year of storage
1) *Shinriki* (average of 9 samples)	% 122,0	% 126,6	% 129,4	% —
2) *Kibiko* „	116,2	120,7	126,1	126,0
3) *Shinriki* (average of 10 samples)	113,1	123,1	127,1	—

Note. 1) These samples are harvested in 1915.
2) 3) „ „ „ „ „ 1916.

It would seem that the swelling ability of hulled rice in water (see IV), and the increases in volume of boiled rice "Kamabue" would go hand to hand, but the reverse is true.

The taste of boiled rice deteriorates gradually during the years of storage. Especially in summer the taste deteriorates suddenly. The writer's experiments as well as common opinion prove that, from the point of view of taste of boiled rice, two or three years are the maximum length of time allowed for storing the hulled rice grains in straw-bags. It is safe to say that the deterioration in the taste of the rice is due to physical and chemical changes in the properties of the rice, damage by insects, mould and other causes. A hot and wet season accelerates the deterioration in the taste, hence rice in storage should be kept cool and dry.

Good rice is sticky but bad one on the contrary is poor in the glutinous element and this quality is the most important one regarding the taste of cooked rice. To determine the relationship between this quality of rice and the length of time of storage the viscosity of the rice paste of the several kinds of rice stored in straw-bags during a period of several years was studied. According to the results of the experiments the viscosity of the rice paste decreases suddenly during summer, and especially after the lapse of three summers the viscosity of the paste decreases in a great degree. As is well known, the taste of cooked rice is much affected by its stickiness and the stickiness of the rice can be determined by the viscosity of the rice paste. The experiment proves that the deterioration of the taste and decreation of viscosity of rice paste go hand to hand and that from the points of view the safety limit of duration of storage of hulled rice in straw-bags in a common granary is perhaps two years.

IX. Rational method of storing hulled rice grains.

The deterioration of qualities of rice takes place gradually during the time that it is stored. Particularly in a hot season, June—September it takes place in a great degree. The problem of storage is therefore especially important for the storage of rice in summer or in a tropical region. For the storage of hulled rice it is very important to dry the grains at the harvest-time, but also to protect them from moisture during the time of storage, to cool the grains and the granary air in summer and to keep insects in check. Air tight should be a good condition for the storage[1]. To satisfy these conditions it is of first importance to make the situation, construction and arrangements of a granary rational in order to keep the granary air always cool and dry. The situation on an elevation, an enclosure with trees, thick walls and roof, good ventilation but small windows, high roofing and flooring, air drying and cooling arrangements etc, are the important items to be studied for the construction of a granary.

One of the questions about storing rice is the advantages and disadvantages of the use of straw-bags which are used only in Japan. The straw-bags are very convenient for transportation, shipping and pileing up, but are not well adapted for the protection of rice from atmospheric moisture and keeping out insects. For storing rice in safety, the improvement of bags is very important and the use of a strong japanese paper bag inside of the straw-bags is, according to the writer's experiment, fairly effectual for storing rice. Strong tightening of straw-bags is also very important for the protection of rice from moisture. An another unsolved question is that, which is better, a straw-bag or a jute-bag for the storage of rice, and this must be studied from the point of view of keeping of good qualities of rice, convenience and economy.

The storing of hulled rice is very common in Japan, while in foreign countries only unhulled rice is stored. Unhulled rice can be stored in safety as a matter of cause. Not very long ago it was common to store unhulled rice in Japan as a provision against shortage. The method of storing unhulled rice might be studied further.

White rice is very rarely stored in Japan, because the deterioration of quality takes place more rapidly than that of hulled rice. The sale of white rice is much more profitable to the farmer than the sale of either hulled rice or unhulled, therefore the problem of storage of white rice is important to the farmer.

The drying of the grains and their protection from the moisture are the foundamental conditions for the storing rice, as already stated. There are many ways of drying the rice; drying by the sun's heat; drying by means of chemicals; drying in an oven; drying before hulling or drying after hulling. The drying by heat of the sun before hulling is the most common, easy and economical method in Japan, but in some localities as in North-Japan, the drying by the sun's heat is not enough, and the drying in an oven is necessary. To dry the grains too much, the taste of boiled rice is but to deteriorate. According to the writer's opinion a moisture of 13% or less should be suitable for the storing of hulled rice grains.

For the protection of the rice from atmospheric moisture an air-tight appartment is the best. It keeps the insects in check absolutely. Once the writer sealed hulled rice and *Calandra Oryzae* together in a bottle hermetically, but leaving enough air inside of the bottle. It was observed that these insects did not increase in the least and the rice grains were preserved for a long while in a good condition. The sealing of a granary hermetically is in practice very difficult but making a silo or a tin can for rice is not so difficult.

Summary.

1) In Japan at present the storage of rice is carried out generally in the state of hulled rice. The hulled rice, however, being much damaged by insects and mould, it is a very important problem to study a rational method of storing.

2) From 1915 until to day the writer has studied the problem of storing rice, particularly about the change of physical properties of hulled rice during the time of storage. The several kinds of rice were stored in a granary of the Ōhara-Institute.

3) The temperature of hulled rice in a straw-bags is always different from the granary temperature. In summer and autumn the former is higher than the latter generally, but in the upper part of a great granary it is

just contrary, because the air temperature increases much more than the rice temperature with the height in a granary.

4) In winter and spring, on the contrary to (3), the rice temperature is always lower than the granary temperature and in the upper part of a great granary it is same.

5) As the granary and rice temperature rises very much with the height, it is very important in the hot season by good ventilation or some other equipments to prevent the increase of temperature in the upper part of the granary.

6) The temperature of rice varies mainly with the air temperature of the granary, but the moisture of rice and also several kinds of insects in the straw-bags play a great roll in the raising of the rice temperature.

7) The humidity of the air in a granary decreases with the increase of height and it is important by some equipments to dry the air in the lower part of the granary.

8) According to the season, the moisture of rice grains varies greatly; in June and July it is greatest, and in December and January least; since it is greatly affected by the atmospheric humidity.

9) If various kinds of rice of different moisture are stored together, it will be seen that their moisture gradually changes apporoaching to each other and finally almost coinciding, but after several years the rice grains lose water gradually and become dry. In this case it is observable that the rice, that was in the beginning driest lost most water. At last the moisture of rice grains becomes very different according to the degree of dryness of the grains in the beginning.

10) If rice is stored a long time in straw-bags in a granary, its moisture decreases gradually during the years that they are stored.

11) The volume weight of hulled rice grains varies greatly according to the season; in July, August, September it is small, especially in August least, and in January and February great, especially in January greatest. Since it is greatly affected by the atmospheric humidity.

12) In general, the volume weight of hulled rice grains increases gradually during the time of storage. When the grains were damaged by insects however, their volume weight decreases suddenly.

13) The water absorbing capacity and swelling ability in water of rice, which is stored in straw-bags, decreases regularly with the length of storage.

14) Let x be the number of months, during which the rice grains are stored, let y be the percentages of increase in volume or weight and let a and n be constants, then there will result the following equation: $y = ax^n$.

15) By experiments and calculations the constants a and n can be determined. Take any hulled grains in storage. If the percentage of increase in volume or weight of grains in water are investigated, then the number

of months of storage of the rice grains can be easily found by the equation, which were determined.

16) When rice grains are soaked in water, the percentage of increase in volume is much greater than that of weight.

17) The moisture of rice grains has an effect upon the water absorbing capacity and swelling ability, as may already be known, but this effect is much more slight than that caused by the length of storage.

18) Notwithstanding the seasonal variation in the moisture of the grains, the water absorbing capacity and the swelling ability of water soaked rice grains varies only in the least degree with the season.

19) The hardness of the rice kernels stored in straw-bags decreases with the lapse of time, during the first 2—3 years, but after several years it increases again.

20) According to the season, the hardness of rice grains varies greatly, since it is greatly effected by the atmospheric humidity. In July—September it is least, November—February greatest.

21) The material lost by polishing the rice grains decreases with the length of storage, when the rice is stored without the damage by insects and mould.

22) According to the season, the material lost by polishing varies greatly. In July and August it is greatest and in December—February least, because it is greatly effected by the atmospheric humidity.

23) The hulled rice in straw-bags keep its germination power until the next May perfectly; in June—July the germination power decreases to 60—80%, in August to 11—30%, in September to 5—10% and in October to less than 1%. The longevity of the kernels is scarcely one year.

24) "Kamabue" of rice increases regularly with the length of time of storage. It seems as if the "Kamabue" and swelling ability of the water soaked rice should go hand to hand, but both qualities are just the contrary.

25) Besides, the writer studied the variations of weight of 1,000 grains, taste of cooked rice, viscosity of rice-paste and activities of several kinds of enzymes, during the time of storage.

26) For the storage of hulled rice it is very important to dry the grains at first, to protect it from moisture during the time of storage, to cool the grains and the granary air in summer and keep the insects in check. Air tight appartments are a good condition for the storage. In order to satisfy these conditions the situation and construction of the granary, improvement of bags, kinds of rice, method of drying must be studied further.

Literature.

1) DENDY A., Report on the effect of air-tight storage upon grain insects, Part I. Report of the Grain Pests (War) Committee, Royal Society, London, No. 1, 1918.

2) DENDY A. & ALKINGTON H. D., Report on the effect of air-tight storage upon grain insects. Part II. Report of the Grain Pests (War) Committee, Royal Society, No. 3, 1918.

3) ——— & ———, On the prevention of heating in wheat by means of air-tight storage. Report of the Grain Pests (War) Committee, No. 5, Royal Society, 1919.

4) ——— & ———, Report on the effect of air-tight storage upon grain insects, Part III Report of the Grain Pests (War) Committee No. 6, Royal Society, 1920.

5) ——— & ———, Report on the vitality and rate of multiplication of certain grain insects under various conditions of temperature and moisture. Report of the Grain Pests (War) Committee, No. 7, Royal Society, 1920.

6) KONDO, M., Untersuchungen über das Volumgewicht des enthülsten Reiskornes. Ber. d. Ōhara-Inst. f. Landw. Forsch. Bd. 1, Heft 1, 1916, S. 1—26.

7) KONDO, M. & TAKEDA M., 近藤, 武田. 米穀貯藏ニ關スル研究. 特ニ貯藏中ニ於ケル物理學的米質ノ變化ニ就キテ. 大原農業研究所特別報告, 第二號, 大正十四年.

8) NOBBE, F., Handbuch der Samenkunde 1876, S. 120—121.